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Office of Naval Research Equipment Grant Report

Durip Grant No. N00014-89-J-1326, (MTU # 881120)

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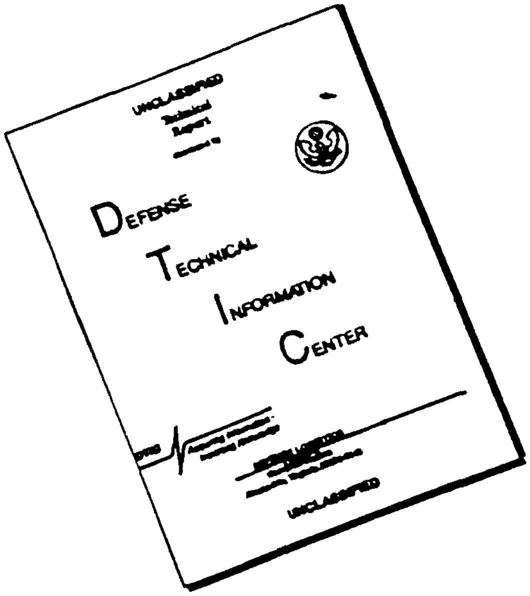

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Abstract

In 1989 a DURIP grant for scientific equipment was awarded to the Department of Physics of the Michigan Technological University with Professor S. A. Marshall to be principal investigator. This grant, in the amount of $135,000, was administered through the Office of Naval Research with Dr. Gabriel Roy the grant monitor. Its purpose was to modernize and up grade scientific equipment used by research oriented universities having DoD contracts. In addition, the funds for this grant were to be used to further the efforts of the Office of Naval Research contract No. N00014-89-J-1966 issued by the . The purpose of this contract was to establish a noninvasive experimental methodology for determining, (a) density, (b) velocity, and (c) vorticity of a flowing medium using the methods of electron paramagnetic resonance imaging. To develop this methodology, specialized equipment was purchased for the purpose of constructing a pulsed or time domain electron paramagnetic resonance spectrometer. Such a spectrometer is now in partial operation and work has begun on an up dated version. A total of $144,533 has been expended on equipment for this spectrometer and its associated signal processing equipment. The excess $9,533 supplied was made up by funds taken from the Office of Naval Research contract No. N00014-89-J-1966.

Discussion

The purpose of this research effort is to establish a methodology for determining certain dynamical parameters of a compressible fluid in motion. It is supported by the Office of Naval Research under contract No. N00014-89-J-1956. These dynamical flow parameters are: (a) density, (b) velocity, and (c) vorticity. It is intended that these three parameters be determined at sufficient number of fluid volume cells, voxels, to provide useful information on flow dynamics. These voxels are to be taken at points in planes perpendicular to the flow axis, tomes, with the tomes distributed contiguously along the flow direction. The widths of the tomes are to be determined by demands on the grain details of the flow characteristics.

At the present, one result of our experiments on the imaging of molecular oxygen under static fluid conditions is that a high quality image of gaseous molecular oxygen having a slice thickness of 0.1 millimeter or 100 micrometers can be obtained. However the cost in data accumulation time and computer image data processing time is of the order of eight or so hours, which is considerable. If image quality and cellular resolution requirements are relaxed we estimate that tome thickness resolutions of the order of 1.0 millimeter can be achieved in a matter of a few hours. It should be mentioned that these preliminary results on spatial resolution and data accumulation time estimates are based upon our former use of frequency domain spectroscopy or CW spectroscopy.

The matter of spatial resolution is based upon the quality of gradient magnetic field coil design and coil performance. As of this report, our gradient magnetic field coils were designed for our former frequency domain spectrometer. More sophisticated gradient magnetic field coils are in the process of being designed and constructed. These new or smart coils would be used along with our new time domain spectrometer. Smart gradient magnetic field coils are designed to produce highly uniform gradient magnetic fields over a significant region of the specimen volume and close to zero magnetic field over the same volume, that is, in much the same manner as a Helmholz coil do but with greater efficiency.

Frequency domain spectroscopy generally requires data accumulation times of the order of several minutes for each back projection and as many as 180 to 360 back projections for per tome. Typically, our most efficient data taking procedures have taken as long as eight hours per tome with azimuthal angle increments of one to two degrees of arc. The principal bottleneck in this process of data accumulation is (a) that of reorienting the magnetic field direction so as to provide azimuthal angle increments and (b) that of scanning through the frequency or magnetic field domain of a resonance absorption line.

Many of these difficulties can be avoided through the use of time domain spectroscopy. Using this technique, spectral data can be obtained from either the Free Induction Decay signal, FID, or from the electron spin echo signal of an electron spin system. There is still a more compelling reason for going over to time domain spectroscopy and thereby abandoning frequency domain spectroscopy. The reason is that the ultimate goal of this project is to establish a methodology for determining flow parameters, these being, density, velocity, and vorticity. Frequency domain spectroscopy is basically a d.c. type measurement which necessarily means that time dependent phenomena are averaged out to yield time averages. As a consequence, although fluid density can be determined, neither the velocity nor vorticity can be determined by this technique. However, these two latter flow parameters can in principle be determined by electron spin echo spectroscopy. The details of how velocity and vorticity can be determined for a fluid in motion have been developed in a previous report submitted to O.N.R. contract

Figure 1 is a schematic diagram of the electron spin echo spectrometer. The figure does not include a diagram of the gradient magnetic field coils required for the production of tome images nor of the pulsed gradient field coils required to develop gradient magnetic fields required for determining flow field velocities and vorticities.

A replica of an electron spin echo taken at 77 K of the EPR signal generated by the free radical molecule ion CO_3^{3-} produced in gamma-irradiated single crystal calcium carbonate is presented in Figure 2a. This system was chosen because of the ease of producing the free induction decay signal as well as the electron spin echo signal. At this temperature, the CO_3^{3-} molecule ion has a resonance absorption line width which is of the order of 15 milligauss, its frequency equivalent being 45 kilo-Hertz. Figure 2a is a photograph of the electron spin echo signal taken from a digital oscilloscope. It provides a record of most of the temporal parameters used to produce the echo signal. In Figure 2b, the signal information captured by the digitizer is transferred to a desk-top computer. A graphics program then produces an x-y tracing of the signal captured by the digital oscilloscope.

Further work on the time domain electron spin echo spectrometer is currently in progress and will continue along the lines of producing a more flexible and versatile spectrometer tailored to the task of magnetic resonance imaging and capturing image information required to produce such three dimensional flow information as fluid density, and such stream distribution information as velocity and vorticity.

The principal investigator of this contract is deeply grateful to the Department of Defense and the Office of Naval Research for making this DURIP equipment grant possible. In particular, special thanks are directed to Dr. Gabriel Roy of the Office of Naval Research for having demonstrated confidence in the overall mission of the project and by complementing the

project's equipment allowance with this grant.

Further development involving the use of equipment procured by this DURIP grant for the purpose of establishing a noninvasive methodology for producing density, velocity, and vorticity information on the stream field of a fluid will be presented in a future progress report to be delivered to the Office of Naval Research for the parent O.N.R.contract No. N00014-89-J-1966 .

On the following pages an account is given of the expenditures committed to this O.N.R. contract by the DURIP funds.

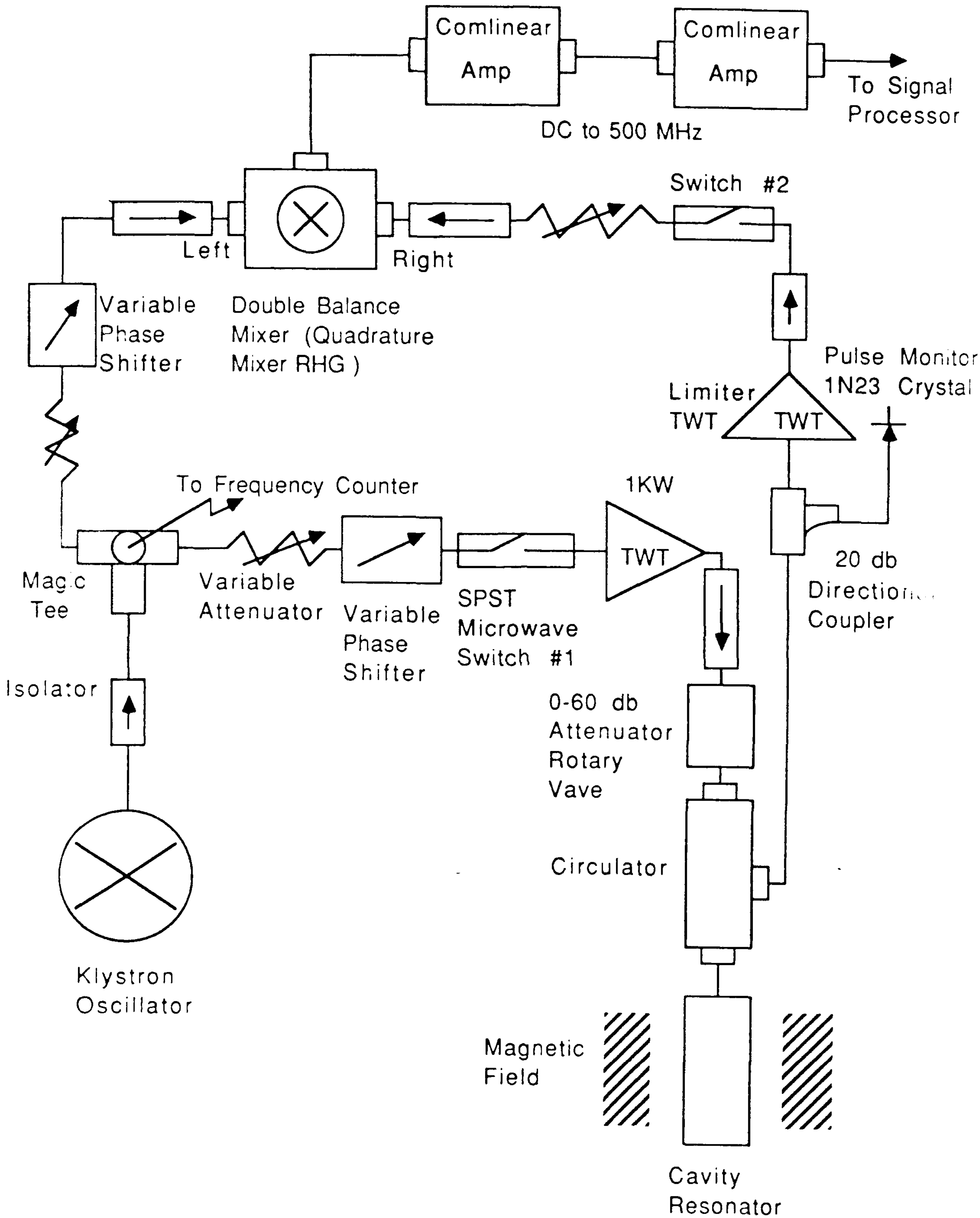
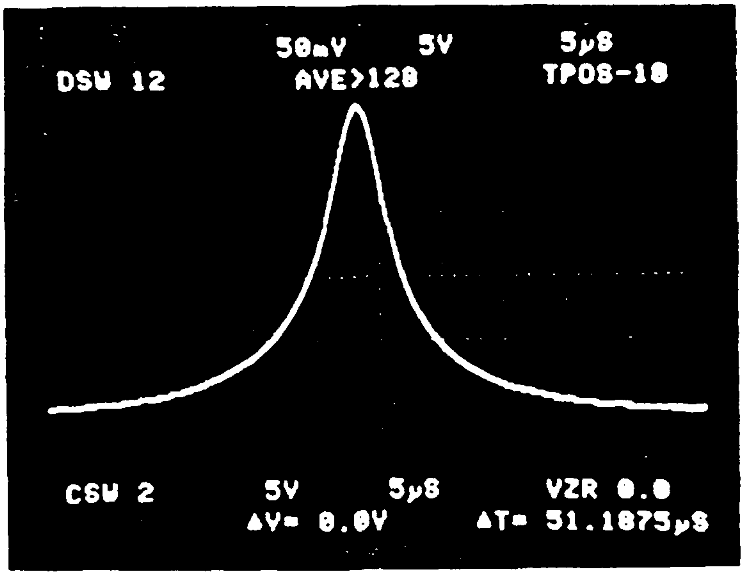


Figure 1. Schematic diagram of the EPR spin echo spectrometer.



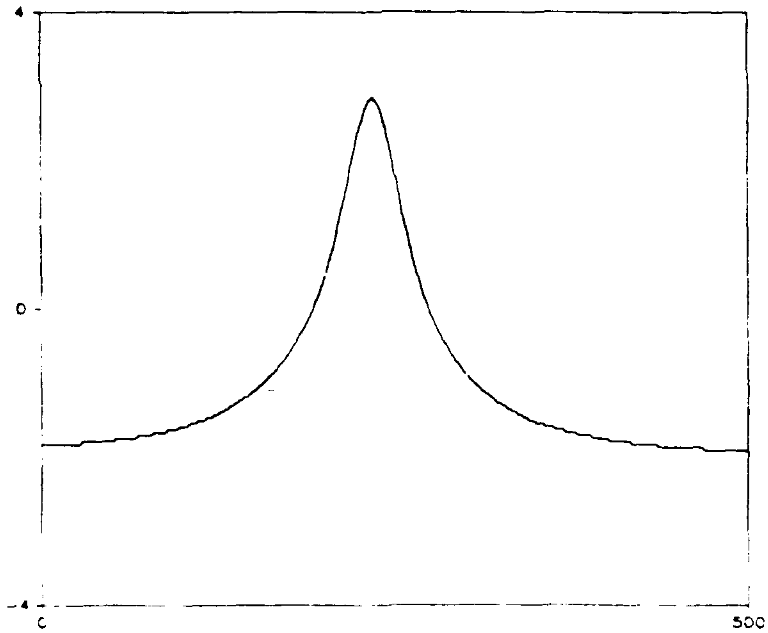


Figure 2(a). An oscilloscope's presentation of the spin echo of the CO_3^{3-} molecule ion in single crystal calcite taken at [illegible] K.
Figure 2(b). A computer graphics representation of this echo.

Appendix

DoD DURIP Grant
No.N00014-89-J-1326, (MTU # 881120)

Date	Company Name & Address	Description	Cost
4/0[illegible]/89	MTU Bookstore	IBM Proprinter X24	$ 505.00
7/02/89	Coaxial Connectors, Inc. 89 Hancock Street Braintree, MA 02184	SMA plugs & jacks plus a T adapter 617-849-3212	$ 940.00
1/02/89	Pasternack Enterprises PO Box 10759 Irvine, CA 92714	Cable, SMA male & female type (714)261-1920	$ 843.50
7/02/89	ARRA, 15 Harold Court Bay Shore, NY 11706	X-band microwave phase shifter	$ 380.00
7/02/89	Waveline Co. Box 718 W. Caldwell, NJ 07006	Vane-Attenuator (8-12.4 GHz) Waveguide-coax adapter	$ 2,500.00 $ 370.00
7/02/89	Pasternack Enterprises P.O.Box 10759 Irvine, CA 92714	Coax 50 ohms RG 142 Series 6", 12", 18" (8 ea), 24", 36" (2 ea)	$ 642.00
2/03/89	Comlinear Corp 4800 Wheaton Drive Fort Collins, CO 80525	CLC-100 linear amplifier range plus SMA-Female input/output connectors	$ 722.00
0/03/89	Tektronix, Inc. 4660 Churchill Street St. Paul, MN 55126 616-484-8571 (Education Contribution from Tek. - $ 4,795.00)	Oscilloscope, digital Amplifier, DC-1 GHz Amplifier, DC-600 MHz Diff Comp, DC-150 MHz IBM utility for GPIB Data transfer controller	$15,500.00 $ 2,850.00 $ 2,550.00 $ 3,200.00 $ 470.00 $ 300.00
0/03/89	Davilyn Corp. 13406 Saticoy St. N. Hollywood, CA 91605	Tubes (15) 1-800-235-6222	$ 145.00
1/04/89	Polytron Devices, Inc. P.O.Box 398 Patterson, NJ 07544	Power supply socket (4) Encapsulated power S (4) 201-345-5885	$ 161.00
3/04/89	Midisco 61 Mall Drive Commack, NY 11725 1-800-637-4353	Termination, 50 ohm (SMA) Circulators (SMA) (10) Directional Couplers (SMA) D.C. Block (SMA)	$ 4,122.00

1/05/90	Image Processing Software 6409 Appalachian Way P.O.Box 5016 Madison, WI 53705	Proofwriter Version 2.7 608-233-5033	$ [illegible]
8/05/89	Vecktronics 113 Lincoln Blvd. Middlesex, NJ 08846	Phase Shifter (1) plus all connectors 201-356-2377	$ 1,500.00
8/05/89	Commercial Systems Houghton, MI 49931	Curtis Computer Tool Kit 906-482-3990	$ 23.95
5/05/89	Central Scientific Co. 11222 Melrose Ave. Franklin Park, IL 60131	Gauss meter, Hall effect 1-800-262-3626	$ 514.25
1/06/89	Edlie Electronics 2700 Hempstead Turnpike Livitown, NY 11756	Silver print (3) 1-800-645-4722	$ 69.95
5/07/89	Watkins Johnson Co 3333 Hillview Ave. Stanford Industrial Park Palo Alto, CA 94304	X-band low noise traveling wave tube amplifier 415-493-4141 ext 2391	$ 7,145.00
5/09/89	Kenosha Computer Center 2233 91st Street Kenosha, WI 53140	Intel math coprocessor 1-800-255-2989	$ 231.00
5/09/89	Horstmann Software Corp. 140 E. San Carlos, San Jose, CA 95150	ChiWriter	$ 124.95
5/09/89	Digi Key Corp. 701 Brooks Ave., S.Box 677 Theif Rvr Falls, MN 56701	Parallel connector male & female (3 ea)	$ 31.59
7/09/89	Commercial Systems Houghton, MI 49931	Printer ribbon (5) 906-482-3990	$ 32.75
1/0[illegible]/89	Computer Distributors Midwest Inc. 2720 S. Des Plaines Ave Des Plains, IL 60018 1-800-345-0532	Coaxial cable Coax connector (50) Crimp tool (1) Cable trim tool (1) Torque wrench (1)	$ 136.[illegible] $ 335.00 $ 435.00 $ 309.75 $ 78.55
1/03/90	William A. Sales Corp. 419 Harvester Court Wheeling, IL 60090	H-cell 708-541-1300	$ 800.00

[illegible]	Newark Electronics 1676 Viewpond SE Grand Rapids, MI 49508	Foil shielding tape (copper) (4) 616-455-9190	$ 140.00
/04/90	Davilyn Corp. 13406 Saticoy Street N. Hollywood, CA 91605	Misc. parts	$ 110.00
/04/90	Tektronix, Inc. P.O.Box 4800 Mail Stop 94-860 Beaverton, OR 97076	Instrument cart for oscilloscope Camera for oscilloscope Film (3)	$ 561.00 $ 442.00 $ 42.00
/05/90	Varian Associates 811 Hansen Way, Palo Alto, CA 94303	Magnetic sensor (fieldial Hall effect) 1-800-382-7426	5,302.00
/05/90	Microwave Associates South Ave. Burlington, MA 01803	DBM mixer (coax) 617-275-3000	$ 366.00
/05/90	Stanford Research Systems 1290D Reamwood Ave. Sunnyvale, CA 94089	Time interval counter SR620/01 Oven timebase for above	$ 4,500.00 $ 950.00
/05/90	Johnson Matthey, Inc. AESAR Group 892 Lafayette Rd. Box 1087 Seabrook, NJ 03874	Zinc selenide (250 grams) 1-800-343-1990	$ 397.00
[illegible]	Wavetek Instruments Rockland Systems 9045 Balboa Ave. San Diego, CA 92123	Generator, [illegible] MHz, sweep function, Model 33, crystal stabilized, L.C. display (2 ea)	$ 2,784.00
[illegible]	National Instruments 12109 Technology Rd. Austin, TX 78727	Interface for IBM/PS2 Model 80 (2)	$ 891.00
[illegible]/90	EG&G Princeton Research P.O.Box 2565 Princeton, NJ 08543	2 channel ADC model 4161A 1-800-451-5959	$ [illegible]
[illegible]	MTU Bookstore Houghton, MI 49931	IBM Model 55 SX IBM Laser printer	$ 2,975.00 $ 915.00
[illegible]/90	EG&G Princeton Research P.O.Box 2565 Princeton, NJ 08543	Model 113 pre-amp. (1) Model 4121B boxcar averager (2)	$ 2,375.00 $ 5,970.00

04/1[illegible]/90	Lemo USA, Inc. 335 Tesconi Circle P.O.Box 11488 Santa Rosa, CA 95406	Lemo plug male, 50 ohms (20) BNC female-male adapter (10)	 $ [illegible] $ 140.[illegible]
08/10/90	Stanford Research Systems 1290D Reamwood Ave. Sunnyvale, CA 94089	Computer interface (1) Gated integrator & averager (1) Detector, signal phase lockin w/preamp. (1) 4 channel digital disc. /pulse generator (3)	$ 1,508.14 $ 2,998.14 $ 3,008.04 $10,549.97
11/10/90	Wavetek Corp. P.O.Box 85434 San Diego, CA 94089	Generator, Model 859 50 MHz, programmable pulse	 $12,550.00
11/10/90	Stanford Research Systems 1290D Reamwood Ave. Sunnyvale, CA 94089	Time interval counter w/oven timebase, data acqu. & ctrl prog.	$ 5,450.00 $ 500.00
15/1[illegible]/90	Amplifier Research 160 School House Rd. Souderton, PA 18964	Amplifier, radio freq. model 10W1000 continuous 1 pulse power	 $ 7,700.0[illegible]
15/10/90	Kepco, Inc. 131-38 Sanford Ave. Flushing, NY 11352	Power supply current & voltage stabilizer (2) interface for above (2)	 $ 5,338.00 $ 2,136.00
28/1[illegible]/[illegible]	Kepco, Inc. 131-38 Sanford Ave. Flushing, NY 11352	Power supply current & voltage stabilizer (1) interface for above (1)	 $ 2,669.00 $ 1,068.00
01/1[illegible]/90	Tektronix, Inc. P.O.Box 4[illegible] Beaverton, OR 97076	Oscilloscope-analogue 100 MHz, rackmount instument (less 15%)	 $ 3,268.25
05/11/90	Procomp Computer Prod. 72 W Maple Troy, MI 48084 1-800-[illegible]-7344	HP plotter (option-1) model 7474A model 7475A Two cables, HP 10833S & HP 17355[illegible]	 $ 2,045.76 $ 2,045.76 $ [illegible]
14/[illegible]	Phillips Scientific 305 Island Road Mahwah, NJ 07430 201-934-8015	NIM bin w/[illegible] monitor NIM power supply qd. g/d generator var. gain amplifier.	$ [illegible] $ 955.0[illegible] $ 1,475.0[illegible] $ 2,390.0[illegible]